PATENT

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Applicant	:	Robindra B. Joshi, et al.
Application No.	:	09/826,969
Filed	:	April 4, 2001
Title	:	SYSTEM AND METHOD FOR MULTI-CARRIER MODULATION
Grp./Div.	:	2631
Examiner	:	Not Assigned
Docket No.	:	39773/RJP/B600

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Post Office Box 7068
Pasadena, CA 91109-7068
November 1, 2001

Commissioner:

Please amend the above-identified application as follows:

In the Claims:

Please amend claim 1 to read as set forth below. Please cancel claim 2. Please add new claims 3 - 27 as set forth below.

1. (amended) A method of compensating for carrier frequency and phase errors of a received multi-carrier modulated signal, the received multi-carrier signal including data tones for transmitting data and training tones for error correction, comprising:

time domain down converting the received multi-carrier signal to base-band to provide a down-converted signal, the down-converted

signal including a plurality of data tones for transmitting data and training tones for carrier phase error correction;

sampling a training tone of the down-converted signal to provide received data samples;

providing a reference signal derived from the training tone of the down-converted signal; and

estimating phase errors from a phase difference between the training tone and the reference signal derived from the training tone of the down-converted signal to provide a plurality of received sample phase error estimates for each data tone.

3.(new) A method of compensating for carrier frequency and phase errors of a received multi-carrier modulation (MCM) signal, the received multi-carrier signal including information-bearing data tones and known-reference training tones, comprising:

time domain down-converting the received multi-carrier signal to base-band to provide a down-converted signal, the down-converted signal including a plurality of data tones for transmitting data and training tones for carrier phase error correction;

time-domain down-converting each of the plurality of training tones to base-band to provide time-domain phase samples of each training tone;

providing a reference signal derived from the training tone of the down converted signal;

estimating time domain phase errors from a phase difference between the time-domain phase samples of each training tone and the reference signal derived from the training tones of the down-converted signal to provide a plurality of time domain received sample phase error estimates for each time-domain received data sample of the received multi-carrier signal;

coherently combining the time domain received sample phase error estimates of each of the plurality of training tones to provide a

single coherently combined time-domain phase error estimate;

applying the single coherently combined time-domain phase error estimate to the time-domain down-converted received multi-carrier signal to compensate for MCM signal frequency and phase errors; and

frequency domain converting a compensated down-converted received multi-carrier signal for further digital signal processing.

4.(new) A method of compensating for carrier frequency and phase errors of a received multi-carrier modulation (MCM) signal, the received multi-carrier signal including information-bearing data tones and known-reference training tones, comprising:

time domain down-converting the received multi-carrier signal to base-band to provide a down-converted signal, the down-converted signal including a plurality of data tones for transmitting data and training tones for carrier phase error correction;

time-domain down-converting each of the plurality of training tones to base-band to provide time-domain phase samples of each training tone;

time-domain down-converting each of the plurality of data tones to base-band to provide time-domain phase samples of each data tone;

providing a reference signal derived from the training tone and data tones of the down converted signal;

estimating time domain phase errors from a phase difference between the time-domain phase samples of each training tone and the reference signal derived from the training tones and data tones of the down-converted signal to provide a plurality of time domain received sample phase error estimates for each time-domain received data sample of the received multi-carrier signal; and / or

estimating time domain phase errors from a phase difference between the time-domain phase samples of each data tone and the reference signal derived from the training tones and data tones of the down-converted signal to provide a plurality of time domain received

sample phase error estimates for each time-domain received data sample of the received multi-carrier signal;

coherently combining the time domain received sample phase error estimates of each of the plurality of training tones and also of each the plurality of data tones to provide a single coherently combined time-domain phase error estimate;

applying the single coherently combined time-domain phase error estimate to the time-domain down-converted received multi-carrier signal to compensate for frequency and phase errors; and

frequency domain converting a compensated down-converted received multi-carrier signal for further digital signal processing.

5.(new) A method of compensating for carrier frequency and phase errors of a received multi-carrier modulation (MCM) signal, the received multi-carrier signal including information-bearing data tones and known-reference training tones, comprising:

demodulating the multi-carrier signal to produce an initial set of MCM data decision estimates;

time domain down-converting the received multi-carrier signal to base-band to provide a down-converted signal, the down-converted signal including a plurality of data tones for transmitting data and training tones for carrier phase error correction;

time-domain down-converting each of the plurality of training tones to base-band to provide time-domain phase samples of each training tone;

time-domain down-converting each of the plurality of data tones to base-band to provide time-domain phase samples of each data tone;

providing a reference signal derived from the training tones of the down converted signal;

providing a second reference signal derived from the initial set of MCM data decision estimates determined during an initial demodulation process; and

estimating time domain phase errors from a phase difference between the time-domain phase samples of each training tone and the reference signal derived from the training tones of the down-converted signal to provide a plurality of time domain received sample phase error estimates for each time-domain received data sample of the received multi-carrier signal; and/or

estimating time domain phase errors from a phase difference between the time-domain phase samples of each data tone and the reference signal derived from the initial set of MCM data decision estimates determined during the initial demodulation process, to provide a plurality of time domain received sample phase error estimates for each time-domain received data sample of the received multi-carrier signal;

coherently combining the time domain received sample phase error estimates of each of the plurality of training tones and also of each the plurality of data tones to provide a single coherently combined time-domain phase error estimate;

applying the single coherently combined time-domain phase error estimate to the time-domain down-converted received multi-carrier signal to compensate for frequency and phase errors; and

frequency domain converting a compensated down-converted received multi-carrier signal for further digital signal processing.

6.(new) A method of compensating for carrier frequency and phase errors of a received multi-carrier modulation (MCM) signal, the received multi-carrier signal including information-bearing data tones and known-reference training tones, comprising:

demodulating the multi-carrier signal to produce an initial set of MCM data decision estimates;

time domain down-converting the received multi-carrier signal to base-band to provide a down-converted signal, the down-converted signal including a plurality of data tones for transmitting data and

training tones for carrier phase error correction;

time-domain down-converting each of the plurality of training tones to base-band to provide time-domain phase samples of each training tone;

producing refined time-domain phase samples of each training tone by removing an estimate of the inter-carrier interference derived from both the training tones of the down-converted signal and the initial set of MCM data decision estimates determined during the initial conventional demodulation process;

time-domain down-converting each of the plurality of data tones to base-band to provide time-domain phase samples of each data tone;

producing refined time-domain phase samples of each data tone by removing an estimate of the inter-carrier interference derived from re-modulation of both the training tones of the down-converted signal and the initial set of MCM data decision estimates determined during the initial conventional demodulation process;

providing a reference signal derived from the training tones of the down converted signal;

providing a second reference signal derived from the initial set of MCM data decision estimates determined during the initial conventional demodulation process; and

estimating time domain phase errors from a phase difference between the refined time-domain phase samples of each training tone and the reference signal derived from the training tones of the down-converted signal to provide a plurality of time domain received sample phase error estimates for each time-domain received data sample of the received multi-carrier signal; and/or

estimating time domain phase errors from a phase difference between the refined time-domain phase samples of each data tone and the reference signal derived from the initial set of MCM data decision estimates determined during the initial conventional demodulation process, to provide a plurality of time domain received sample phase

error estimates for each time-domain received data sample of the received multi-carrier signal;

coherently combining the time domain received sample phase error estimates of each of the plurality of training tones and also of each the plurality of data tones to provide a single coherently combined time-domain phase error estimate;

applying the single coherently combined time-domain phase error estimate to the time-domain down-converted received multi-carrier signal to compensate for MCM signal frequency and phase errors; and

frequency domain converting a compensated down-converted received multi-carrier signal for further DSP signal processing.

7.(new) A multi-carrier transmission system for carrier phase and frequency error correction comprising;

a multi-carrier modulation transmitter; and

a multi-carrier modulation receiver including a down conversion circuit and a training tone tracking circuit, the multi-carrier modulation receiver being coupled to receive a signal transmitted from the multi-carrier modulation transmitter, the received signal being applied to the down conversion circuit to produce a down converted signal, the down converted signal being applied to the training tone tracking circuit to correct phase and frequency errors and producing a phase and frequency error compensated signal prior to demodulating the phase and frequency error compensated signal.

8.(new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 7, wherein the multi-carrier modulation receiver is disposed as an integrated circuit upon a substrate.

9.(new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 7, wherein the training tone tracking circuit includes:

a training tone tracking PLL having an input coupled to a training tone tracking circuit input; and

a multiplier having a first input coupled to the output of the training tone tracking PLL, a second input coupled to the training tone tracking circuit input, and an output coupled to an output of the training tone tracking circuit.

10.(new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 9, wherein the training tone tracking PLL includes:

a phase detector having an input coupled to the training tone tracking PLL input;

a loop filter having an input coupled to an output of the phase detector; and

a frequency synthesizer having an input coupled to an output of the loop filter, and a frequency synthesizer output coupled to a training tone tracking PLL output and to a reference frequency input of the phase detector.

11.(new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 9, wherein the training tone tracking PLL includes a second order phase locked loop.

12.(new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 10, wherein the loop filter is a first order loop filter.

13. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 7, wherein the training tone tracking circuit includes:

a training tone tracking PLL having an input coupled to a training tone tracking circuit input;

a matching delay circuit wherein the matching delay circuit input is coupled to the training tone tracking circuit input; and

a multiplier having a first input coupled to an output of the matching delay circuit, a second input coupled to the training tone tracking PLL output, and an output coupled to an output of the training tone tracking circuit.

14. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 13, wherein the training tone tracking PLL includes:

a phase detector having an input coupled to the training tone tracking PLL input;

a loop filter having an input coupled to an output of the phase detector; and

a frequency synthesizer having an input coupled to an output of the loop filter, and a frequency synthesizer output coupled to a training tone tracking PLL output and to a reference frequency input of the phase detector.

15. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 13, wherein the training tone tracking PLL includes a second order phase locked loop.

16. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 14, wherein the loop filter is a first order loop filter.

17. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 14, wherein the phase detector includes:

a tone tracking mixer and filter circuit wherein an input of the tone tracking mixer and filter circuit is coupled to the phase detector input;

a mixer having a first input of the mixer coupled to an output of the tone tracking mixer and filter circuit, and wherein a second input of the mixer is coupled to the phase detector frequency input; and

a phase angle calculation circuit wherein an input of the phase angle calculation circuit is coupled to an output of the mixer.

18. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 14, wherein the phase detector includes:

a plurality of phase error circuits having a plurality of phase error circuit inputs coupled to a phase detector input;

a summing junction circuit having a plurality of summing junction inputs coupled to a respective plurality of phase error circuit outputs;

a complex exponential circuit wherein the complex exponential circuit input is coupled to a summing junction output;

a mixer wherein a first mixer input of the mixer is coupled to a complex exponential circuit output, and a second mixer input of the mixer is coupled to the reference frequency input of the phase detector; and

a phase angle calculation circuit wherein a phase angle calculation circuit input is coupled to an output of the mixer, and wherein an output of the phase angle calculation circuit is coupled to the output of the phase detector.

19.(new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 18, wherein each of the plurality of phase error circuits includes:

a phase error tone tracking mixer and filter circuit wherein the tone tracking mixer and filter circuit input is coupled to the phase detector input;

a channel compensation circuit wherein an output of the tone tracking mixer and filter circuit is coupled to the channel compensation circuit input; and

an arctangent circuit wherein an output of the channel compensation circuit is coupled to an input of the arctangent circuit, and wherein an output of the arctangent circuit is coupled to the output of the phase error circuit.

20.(new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 19, wherein each of the plurality of phase error tone tracking mixer and filter circuits includes:

a first mixer wherein a first mixer input is coupled to the input of the tone tracking mixer and filter circuit and wherein a second mixer input is coupled to a sinusoidal signal set to convert a desired tone, of a plurality of tones, disposed in a multi-carrier signal spectrum to a baseband frequency;

a second mixer wherein a first input of the second mixer is coupled to an output of the first mixer and wherein a second input of the second mixer is coupled to a decision data signal; and

a low pass filter wherein an input of the low pass filter is coupled to an output of the second mixer, and wherein an output of the low pass filter is coupled to the output of the tone tracking mixer and filter circuit.

21. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 14, wherein the phase detector includes:

a plurality of phase error circuits having a plurality of phase error circuit inputs coupled to a phase detector input;

a summing junction circuit having a plurality of summing junction inputs coupled to a respective plurality of phase error circuit outputs;

a complex exponential circuit wherein the complex exponential circuit input is coupled to a summing junction output, and wherein an output of the complex exponential circuit is coupled to the output of the phase detector.

22. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 21, wherein each of the plurality of phase error circuits includes:

a phase error tone tracking mixer and filter circuit wherein the tone tracking mixer and filter circuit input is coupled to the phase detector input;

a channel compensation circuit wherein an output of the tone tracking mixer and filter circuit is coupled to the channel compensation circuit input; and

an arctangent circuit wherein an output of the channel compensation circuit is coupled to an input of the arctangent circuit, and wherein an output of the arctangent circuit is coupled to the output of the phase detector.

23. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 21, wherein each of the plurality of phase error tone tracking mixer and filter circuits includes:

a first mixer wherein a first mixer input is coupled to the input of the tone tracking mixer and filter circuit and wherein a second mixer input is coupled to a sinusoidal signal set to convert a desired tone, of a plurality of tones, disposed in a multi-carrier signal spectrum to a baseband frequency;

a second mixer wherein a first input of the second mixer is coupled to an output of the first mixer and wherein a second input of the second mixer is coupled to a decision data signal; and

a low pass filter wherein an input of the low pass filter is coupled to an output of the second mixer, and wherein an output of the low pass filter is coupled to the output of the tone tracking mixer and filter circuit.

24. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 14, wherein the phase detector includes:

a plurality of phase error circuits having a plurality of phase error circuit inputs coupled to a phase detector input;

a summing junction circuit having a plurality of summing junction inputs coupled to a respective plurality of phase error circuit outputs;

a low pass filter wherein the low pass filter input is coupled to a summing junction output; and

an arc tangent circuit wherein an output of the low pass filter is coupled to an input of arctangent circuit, and wherein an output of the arctangent circuit is coupled to the output of the phase detector.

25. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 24, wherein each of the plurality of phase error circuits includes:

a phase error tone tracking mixer and filter circuit wherein the tone tracking mixer and filter circuit input is coupled to the phase detector input; and

a channel compensation circuit wherein an output of the tone tracking mixer and filter circuit is coupled to the channel compensation circuit input and an output of the channel compensation circcuit is coupled to one of the plurality of summing junction inputs

26. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 21, wherein each of the plurality of tone tracking mixer and filter circuits includes:

a first mixer wherein a first mixer input is coupled to the input of the tone tracking mixer and filter circuit and wherein a second mixer input is coupled to a sinusoidal signal set to convert a desired tone, of a plurality of tones, disposed in a multi-carrier signal spectrum to a baseband frequency; and

a second mixer wherein a first input of the second mixer is coupled to an output of the first mixer and wherein a second input of the second mixer is coupled to a decision data signal and an output of the second mixer is coupled to the input of the channel compensation circuit.

27. (new) The multi-carrier transmission system for carrier phase and frequency error correction of claim 8, wherein the multi-carrier modulation receiver is disposed as an integrated circuit upon the substrate by a CMOS process.

REMARKS

The afore-mentioned application has been amended. No new matter has been added. Entry of the amendment and examination of the aforementioned application as amended is hereby requested.

Attached hereto is a marked-up version of the changes made to the

specification and claims by the current amendment. The attached page is captioned "**Version with markings to show changes made.**"

Respectfully submitted,

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By _____

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VERSION WITH MARKINGS TO SHOW CHANGES MADE

1. (amended) A method of compensating for carrier frequency and phase errors of a received multi-carrier modulated signal, the received multi-carrier signal including [modulated carriers] data tones for transmitting [known] data and [unmodulated carriers] training tones for error correction, comprising:

time domain down converting the received multi-carrier signal to base-band to provide a down-converted signal, the down-converted signal including a plurality of [modulated carriers] data tones for transmitting [known] data and [unmodulated carriers] training tones for carrier phase error correction;

sampling [an unmodulated carrier] a training tone of the down-converted signal to provide received data samples;

providing a reference signal derived from the [unmodulated carrier] training tone of the down-converted signal; and

estimating phase errors from a phase difference between the [unmodulated carrier] training tone and the reference signal derived from the [unmodulated carrier] training tone of the down-converted signal to provide a plurality of received sample phase error estimates for each [modulated carrier] data tone.